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# Evaluation of the requirements for the approval of weld through primers

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*Foreword*

This report was prepared by Mr H C Inward of the Small Engines Division of Rolls Royce Ltd for the Director of Materials/Aviation between September 1967 and June 1970 under former Ministry of Technology contract no KS/3/0531 CB43(a)2.

The work was planned, progressed and administered by Mat (O) 2 under the direction of AD/Mat(O), Ministry of Technology.

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*Summary*

In order to consider a specification for weld through primers, certain parameters were investigated. The effects of different surface treatments and different types of primers on the surface resistance were determined. Welding consistency tests, as evaluated by shear strength, X-ray and metallographic examinations, were carried out. A corrosion test was developed and used to evaluate the effect of weld through primers in minimising corrosion.

The overall assessment was that when using some weld through primers, satisfactory weld quality could be maintained. However, these primers, although reducing the tendency for corrosion, were not completely effective as corrosion inhibitors.

CONTENTS

TABLES



FIGURES

## INTRODUCTION

Spot welding of aluminium has been used as a method of construction in aircraft production for many years. However despite the many advantages some aircraft manufacturers have been reluctant to extend its use. One reason for this is the possible corrosion problem. The spot welding process necessitates the removal of most of the protective oxide film from aluminium before welding, and this factor, together with the crevice effect between the welded surfaces, provides a structure which is highly susceptible to corrosion. Consequently it has been found advantageous to use compounds between the welded surfaces to prevent corrosion. It is a requirement that with the compound in situ between the two aluminium surfaces it shall be possible to spot weld these surfaces together. These compounds may be of various types but are all called for convenience weld-through primers.

The aim of the present work was to determine the parameters by which different primers could be approved to a common specification. The programme was divided into four main stages.

*Stage 1* Comparison of methods of preparing aluminium surfaces prior to spot welding.

*Stage 2* The determination of the time delay that could be tolerated after the application of weld-through primers. For stages 1 and 2 the measurement of surface resistance was the criterion determining the feasibility of subsequent welding.

*Stage 3* Aluminium alloys were welded using selected primers and the quality of the welds was determined by shear tests, X-ray and metallographic examination.

*Stage 4* Corrosion tests were carried out on welded specimens followed by further shear tests.

## EXPERIMENTAL PROCEDURE AND RESULTS

## 1. TEST METHODS

### 1.1 Surface Resistance Measurements

As the quality of spot welds largely depends on the surface resistance of the metals to be welded the effect of different pickling procedures, ageing time after pickling, and the application of the weld through primers on the surface

resistance of a number of aluminium alloys was determined. An apparatus based on the circuit shown in Fig 1 was used for these determinations. Two aluminium panels were placed face to face between the copper electrodes to which a pressure between 1000 and 1600 pounds was applied. A current of 10 amps was passed between the electrodes and the surface resistance calculated from the voltage drop across the faying surfaces.

For all tests the average of triplicate measurements was determined. The range of surface resistance values was between 2 micro-ohms and 5000 micro-ohms. Both with and without primer there was better agreement between triplicate readings in the low range than in the high range of resistance values. Without primer there was an 8 per cent or less variation in the 0-10 micro-ohm range but with readings over 100 micro-ohms there were variations of about 50 per cent. When using primers it was more difficult to obtain consistent readings as the voltage was continuously dropping whilst the electrode pressure was maintained. However in the 0-100 micro-ohm range reasonable agreement of results was obtained.

1.2 Welding Procedure

Welding was carried out with a 100 KVA three phase Sciaky welding machine. The tests were divided into two types: a preliminary test and a consistency test. The preliminary welding test was made on about seven specimens (see Fig 2) to determine the conditions under which the consistency tests could be carried out. The conditions considered included pretreatment methods, the types of primers to be used, the open and closed time applicable to these primers, and the most suitable welding machine settings. The consistency tests using 30 specimens (see Fig 3) determined whether under the conditions selected by the preliminary tests, satisfactory weld quality could be consistently maintained. There was a period of one day between the pickling of the specimens and the next stage - welding without primer or application of primer.

1.3 Assessment of Weld Quality

Three methods were used to determine the quality of the spot welds: X-ray examination, metallographic examination and shear testing. The X-ray examination detected such faults as cracking, porosity, poor shape and lack of fusion. The metallographic method determined the dimensions of the weld with respect to the parent material; faults detected by this method were excess or poor penetration, excessive indentation, cracking, porosity and lack of fusion. The

criterion for the shear tests was that the weld strength should be of a satisfactory order compared with the strength of the parent alloy and the standard deviation of the shear strength for the 20 specimens tested, should not be greater than 5 per cent.

In the preliminary tests all specimens were X-rayed, some were examined metallographically and a few consistency type specimens used for shear tests. In the consistency tests all specimens were X-rayed, 10 examined metallographically and 20 tested for shear strength. The first weld on each specimen was regarded as untypical and disregarded in all inspections of weld quality.

## 1.4 Corrosion Test Methods

The aim of the corrosion tests was to determine a method which could be used to check the effectiveness of weld through primers as corrosion inhibitors. These tests were carried out with the same alloys, primers, type of specimen, preparation and welding conditions as used in the consistency tests. A direct comparison of the results could then be made. 30 specimens were welded for each test and all specimens X-rayed before the corrosion test.

The parts of the specimens which are important from the corrosion aspect are the internal surfaces and the weld nugget. Thus a test that exposes the joint to the possibility of ingress of corrosive agents (sea water) was required. Wedging the surfaces apart was considered but was thought to introduce too many variables. A technique was finally adopted which forced salt water into the welded joint by applying a vacuum: the specimens were placed in a glass tube, the air evacuated with a water pump, synthetic sea water (composition DEF 1053 Method 24) sucked into the tube and any residual air then pumped out. After repressurising the specimens were removed and fixed into polystyrene foam racks inside a polythene bag. To maintain a high humidity in the bag about 30 mls of sea water was added. The bags were then stored at 40°C and the salt water injection procedure repeated every two weeks during the corrosion test. Most of the specimens were removed after 22 weeks but some were tested for a further 6 weeks. All were tested for shear strength and degree of corrosion, and selected specimens examined metallographically for depth of corrosion.

## 2. WELDING OF ALUMINIUM ALLOYS WITHOUT PRIMERS

### 2.1 Alloys Used

| *Alloy* | *Gauge* | *Supplier* | *Batch No* |
|---|---|---|---|
| L71 | 20 swg | High Duty Alloys | 27.E.28 |
| L72 | 20 swg | Aluminium Company of Canada | BY 98 LUMG |
| L72 | 24 swg | Aluminium Company of Canada | SY106 LEYH |
| L73 | 20 swg | High Duty Alloys | 14 D6 |
| L73 | 24 swg | High Duty Alloys | 39.J.29 |
| DTD5070A | 20 swg | High Duty Alloys | 28.J.13 |
| DTD5070A | 22 swg | High Duty Alloys | 12.M.42 |

### 2.2 Pretreatments tested

*a.* Stainless steel wire brushing using a brush made from 30 gauge stainless steel wire.

*b.* Concentrated Nitric Acid SG 1.42 2 vols. / Distilled water 98 vols. — used at 75°C

*c.* Concentrated Sulphuric Acid SG 1.84 10 vols. / Distilled water 90 vols. / Sodium Fluoride 1% w/v — used at room temperature

*d.* Concentrated Sulphuric Acid SG 1.84 1 vol. / Distilled water 99 vols. / Sodium Fluoride 0.1% w/v — used at room temperature

*e.* Aloclene 100 (as supplied by Sunbeam Anti-Corrosives Ltd) 1 vol. / Distilled water 3 vols. — used at room temperature

### 2.3 Effect of Pickling Procedure on Surface Resistance (Figs 4, 5, 6, 7, 8)

The aim of this stage of the programme was to find a pretreatment with which to prepare the aluminium surface for spot welding. This entails removing the oxide film and the

extent of its removal was measured by determining the electrical surface resistance. In practice the most suitable value of this resistance for satisfactory spot welding has not been fully established. For this programme however 50 micro-ohms or less has been considered an acceptable figure. In the aircraft industry parts to be spot welded have often been wire brushed immediately before welding even though they had previously been pretreated by pickling. It was hoped that in this stage a pretreatment would be found which produced a low surface resistance and that this would remain low up till the time of welding. It was found that all the alloys could be pickled to give a surface resistance of 20 micro-ohms or less and that on ageing for ten days or more the resistance was still less than 40 micro-ohms. Both pickle *d* (1 per cent sulphuric acid + 0.1 per cent sodium fluoride) and pickle *e* (Aloclene 100) gave similarly good results for the clad alloys. The effect of pickle time and ageing time on the surface resistance when using Aloclene 100 are given in Figs 4, 5, 6. The pickle time in Aloclene which gave a resistance of less than 20 micro-ohms varied from 2 - 14 minutes, dependent on the alloy. Both gauges of DTD 5070A had limited nickle times of 2 - 4 minutes whereas 20 gauge L72 had a wider range of 2½ - 14 minutes. The specimens with the lowest resistance had the best ageing characteristics. Pickle *c* (10 per cent sulphuric acid + 1 per cent sodium fluoride) produced resistances of 70-1000 micro-ohms so was considered unsuitable. Pickle *b* (2 per cent nitric acid) produced resistances slightly higher than Aloclene 100 (see Fig 7). Based on the resistance measurements, Aloclene 100 was selected as the pretreatment to be used in subsequent welding tests on clad alloys. It also has the advantage of being in common use, easy to control, and can be used at room temperature. 2 per cent nitric acid used at 75°C was found to be the most suitable pretreatment for the unclad alloy L71 (Figs 7, 8). After a pickle time of 20 minutes the surface resistance was less than 20 micro-ohms and remained low on ageing for ten days.

A resistance of 20 micro-ohms or less was produced on the clad alloys by wire brushing and on ageing for ten days the value was about 40 micro-ohms. On L71 however slightly higher resistance of 30-40 micro-ohms was obtained increasing to 80-90 micro-ohms on ageing for ten days.

### 2.4 Welding Results (Table 1)

Preliminary welding tests were carried out on the clad alloys treated in Aloclene 100 for times which gave the lowest surface resistance. As there was little difference of weld quality as a result of the different times, 6 minutes was selected to be used for all the clad alloys in

the welding tests. This time did not necessarily give the lowest surface resistance or the best welds on each alloy but was considered to be a satisfactory compromise. After preliminary welding tests on the unclad alloy L71 using 15 and 20 minute pickle times in 2 per cent nitric acid, 20 mins was selected to be used in subsequent welding tests.

In the consistency tests all the alloys produced welds which had few severe faults when examined by X-ray and had satisfactory and consistent shear strengths (Table 1). However when examined metallographically many of the welds were faulty mainly due to excess penetration. This applied especially to the tests with 20 gauge L73 and 22 gauge DTD 5070A in which at least 85 per cent of the welds had this fault. For 20 gauge L71 and 24 gauge L72 all the welds were satisfactory by all methods of examination.

## 3. WELDING OF ALUMINIUM ALLOYS WITH PRIMERS

### 3.1 Primers used

A number of different types of compounds could be used as weld through primers. Their use will depend on the type of joint and the conditions of service. For this programme three general categories of primer were examined.

#### 3.1.1 Type 1 Primer

A primer, of paint consistency, containing a corrosion inhibitor. It would remain soft for a considerable length of time but could eventually harden on the surface of the metal:

PRI3, a single pack green chromated polyester primer, supplied by Titanine Ltd.

LS5319, a single pack primer supplied by Titanine Ltd.

A DTD 5567 type of primer, modified with different solvents and activators to give a longer cure time - supplied by ICI Paints Division (Base F580/SD/89968 Activator F273/SD/90141).

#### 3.1.2 Type 2 Primer

A paste which would remain soft inside the joint throughout the life of the aircraft structure, and has gap filling properties as well as containing a corrosion inhibitor:

JC5A (lower viscosity type) a chromated polyester paste supplied by Titanine Ltd.

3.1.3 Type 3 Primer

A material which will finally set to a rubber but would remain in a soft condition long enough for the spot welding process to be carried out. This type would have considerable gap filling properties but could also contain a chemical corrosion inhibitor:

PRI422/2, a two part polysulphide compound, supplied by British Paints Ltd.

Polycast 1/512, a two part polyurethane chromated compound, supplied by Alfred Jeffery & Co.

MS9160, a two part silicone compound with variable cure time from ½ to 8 hours, supplied by Midland Silicones Ltd.

3.2 Application conditions for primers

All the primers would be applied to the pickled aluminium surfaces, which would remain open to the atmosphere for a length of time before being closed in preparation for the welding process to be carried out. The period of time between the application of the primer and the closing of the surfaces together is referred to as the OPEN TIME. The primer should remain soft and tacky during this period so that the films of primer on the two welding surfaces will coalesce when the surfaces are closed together.

Ideally weld through primers should remain soft for a considerable length of time, and so could be used between surfaces where there is a long time period between the closing of the surfaces together and the completion of the welding process. This time period is called the CLOSED TIME and would include normal production delays as well as the time needed for inspection of welds and re-welding where necessary.

The primers were applied by brush to the aluminium at 18-23°C one day after pickling and aged for the required open and closed times at the same temperature.

3.3 Resistance measurements (Figs 9, 10 and 11)

These were made on 20 gauge L72 pickled for 6 minutes in Aloclene 100. The surface resistance of the aluminium with primers present depends partly on the electrode pressure. Therefore the most suitable pressure within the range of 1000-1600 lb was first determined for each

primer. Measurements were then made after different open and closed times using this pressure. It was found that readings were higher and more erratic than those made without primers. PRI3 was the only primer with which readings of less than 200 micro-ohms were consistently obtained. (See Figs 9 and 10). With this primer the resistance was less than 100 micro-ohms after a 5 hour open time followed by a 5 day closed time. Results obtained with JC5A were erratic and except after a short open time of ½ hour, resistance increased to over 700 micro-ohms following closed times of 2 days or less. After ½ hour open time followed by a 3 day closed time the resistance was 200 micro-ohms but this increased rapidly to 1000 micro-ohms on extending the closed time to 5 days. Primer F580/SD/89968 (Fig 11) produced sharp increases to 1200 micro-ohms after a 2 hour open time; only a short open time of ½ hour seemed to be of possible use. As Polycast 1/512 sets to a rubber in a few hours the resistance increased to 1000 micro-ohms after 16 hours closed time or less following open times from 2 hours to 5 hours. However after ½ hour open time followed by a 24 hour closed time the resistance was 250 micro-ohms but rapidly increased to 1000 micro-ohms when the closed time was increased to 28 hours.

Testing was discontinued with compounds PRI422/2 and MS9160 as the resistances recorded were > 1000 micro-ohms and very erratic.

3.4 Welding Results

Based on the resistance measurements preliminary welding was carried out using the following primers and open and closed times on 20 swg L72. A second Type 1 primer LS5319 was included at this stage as it had been developed specifically as a weld through primer although no resistance measurements had been made.

| *Primer* | *Open Times* | *Closed Times* |
|---|---|---|
| PRI3 | ½, 2, 5 hours | 1, 3, 10 days |
| LS5319 | ½, 2, 5 hours | 1, 3, 10 days |
| JC5A | ½, 2, 5 hours | 1, 3 days |
| F580/SD/89968 | ½, 1 hour | 2, 5 hours |
| Polycast 1/512 | ½, 2 hours | 2, 5 hours |

The PRI3 and LS5319 specimens gave satisfactory results for all open and closed times although there was slight cracking after 10 days closed time following 2 and 5 hour open times. F580/SD/89968 produced cracking in most of

the welds but was considered of possible use after ½ hour open time and 2 hours closed time. All the specimens with JC5A and Polycast 1/512 had severely cracked welds so no further tests were carried out using these compounds.

As a result of the preliminary tests it was decided to carry out consistency tests under the following conditions.

| *Primer* | *Open Time* | *Closed Time* | *Alloy* | *Gauge* |
|---|---|---|---|---|
| PRI3 | 2 hours | 3 days | L72, L73, L71 DTD 5070A | 20 swg |
| PRI3 | 2 hours | 3 days | L72, L73 | 24 swg |
| PRI3 | 2 hours | 3 days | DTD 5070A | 22 swg |
| LS5319 | 22 hours | 3 days | L71, L72 | 20 swg |
| F580/SD/89968 | ½ hour | 2 hours | L71, L72 | 20 swg |

The results of the tests are given in Table 1, As with the welding tests without primers there was excess penetration in many of the welds and 20 gauge L73 and 22 gauge DTD 5070A again had a high percentage of such faults. 20 gauge L71 was the only alloy with completely satisfactory welds. The shear strength was higher in the tests with primers than those without primers in 8 out of 11 cases and 24 gauge L72 and L73 showed the greatest percentage increase with 23.7 per cent and 20.7 per cent respectively. The main faults in the welds of these alloys were lack of fusion and poor penetration which were not present in the welds without primers. The welds of these alloys with primer were also of a slightly larger diameter than those without primer. These facts, particularly the latter, could account for the greater strength with 24 gauge L72 and L73 when using primer. The alloys which had a large number of welds with excess penetration - 20 gauge L73 and 22 gauge DTD 5070A had a lower shear strength with primer than without primer.

# 4. CORROSION TESTS

## 4.1 X-ray results (Table 2)

An X-ray examination was carried out before the specimens were corroded. Compared with the X-ray results of the spot welds in the consistency tests, the corrosion specimens showed fewer faults. In the consistency tests 14 unsatisfactory welds and 84 other faults (mainly cracking and porosity) were detected by X-ray. In the corrosion tests no unsatisfactory welds were detected and there were only 46 other faults - mainly lack of fusion.

4.2 Shear test results after corrosion (Table 3).

Most of the shear tests after 22 weeks corrosion showed only a slight reduction in shear strength compared with the results from the consistency tests. In seven tests the reduction in strength was less than 5 per cent, in three tests between 5 per cent and 6 per cent and in four tests between 8 per cent and 11 per cent. The other four tests showed an increase in strength. The most significant results were those of the unclad alloy L71. After 22 weeks corrosion the strength of the L71 specimens without primer was 10.4 per cent lower than in the consistency tests, and after a further 6 weeks corrosion there was an additional reduction of 5.2 per cent. The corresponding figures for the specimens with primer PRI3 were 5.3 per cent and 3.7 per cent respectively. With primer LS5319 the reduction was less than 5 per cent and with primer F580/SD/89968 there was an increase in strength of 12.4 per cent possibly due to the fully cured epoxy primer acting as an adhesive. 22 gauge DTD 5070A with and without primer showed a decrease in strength of 9 - 10 per cent.

In 9 out of 11 cases the specimens with primer were stronger than those without primer. As in the consistency tests, 24 gauge L72 and L73 showed the greatest increase in this respect with 17.4 per cent and 12.0 per cent respectively and 22 gauge DTD 5070A and 20 gauge L73 showed a decrease in strength.

4.3 Condition of primers

There was no evidence of any degradation of the primers. The main difference between them was that LS5319 was still very wet inside the joints of most specimens (33 weeks after welding), PRI3 was only slightly tacky and F580/SD/89968 was dry. In no case was the surface of the aluminium inside the joint completely covered by primer. This was probably due to the primer being squeezed out of the joint during welding. This condition also applied to the specimens after the consistency tests. In many specimens there was corrosion underneath the primer as well as in areas not covered by primer.

4.4 General assessment of corrosion (Table 4)

In all tests with and without primer there was corrosion inside the joint on some specimens. The number of specimens showing no corrosion is given in Table 4. 20 gauge L72 showed the greatest number of specimens without corrosion and L71 and 20 gauge L73 the least number. The presence of primer PRI3 slightly reduced the incidence of corrosion

in five cases. On L72 the other two primers prevented corrosion more than PRI3 but on L71 there was little difference. Of the specimens without primer, L71 was obviously the most severely corroded with complete penetration of the thickness of the alloy in 9 specimens out of 20. There was little or no corrosion of the weld nugget in any of the tests and the area immediately round the nugget was often completely free of corrosion.

The five most severely corroded specimens from each test were examined metallographically for depth and type of corrosion.

4.5 Metallographic examination (Table 5)

Based on the average depth of corrosion the L71 specimens with and without primer again showed the greatest corrosion and L72 the least.

In all cases, except L72, the presence of primer reduced the corrosion although this reduction was only marginal in some cases. There were also specific cases where the depth of corrosion on specimens with primer was greater than that on specimens without primer. The greatest reduction in depth of corrosion due to the presence of primer was 72 per cent with the L71 alloy using primer F580/SD/89968.

DISCUSSION

It has been shown that when aluminium alloys have been pickled to a low surface resistance satisfactory welds can be obtained without any further treatment. The effect of ageing after pickling on weld quality has not been determined, but the surface resistance results indicate that satisfactory welds could well be obtainable a number of days after pickling without further surface treatment. This may not be the case if the surface resistance is greater than 20 micro-ohms immediately after pickling which would occur using extended pickle times. The resistance will then increase considerably on ageing. The surface resistance measurements indicate that for each alloy the ageing characteristics are good for only a limited range of pickle times.

The difference in the number of unsatisfactory welds detected by the three methods of weld inspection indicate the need to establish criteria for acceptable spot welds.

It was disappointing that satisfactory welds could only be produced with a few weld through primers and that these were all of one type. The other types of weld through primers, which may be required in some specific cases, in

spite of their disadvantages, may require different standards of assessment.

The corrosion tests with the clad alloys did not give as quick results as would be preferred in an assessment of weld through primers as corrosion inhibitors. It is possible that L71 could be used for this purpose in view of its satisfactory welding properties and its susceptibility to corrosive attack. A quantitative assessment of corrosion by weld strength determinations may only be possible with this alloy. To minimise the reduction in strength due to corrosion outside the joint on L71, the use of a clad alloy with the cladding removed on the inside (adjacent to the primer) may be a more selective condition.

None of the three primers used in the corrosion tests gave complete protection against corrosion but the chromated epoxy primer F580/SD/89968 is preferable to the other two primers in this respect.

## FURTHER WORK

Several compounds are available that can be used as weld through primers and for a few it would be possible to test or 'approve' them to a tentative specification based on this programme of work. Unless the conditions specified for approval were very wide, the number of compounds passing would be few.

The object in using a weld through primer is to eliminate corrosion in a spot welded joint. As the compounds tested have failed in this respect, it is suggested that further work is carried out to develop compounds with improved corrosion resistance, based on the tests described in this report (surface resistance, welding and corrosion).

At the same time it may be possible to 'approve' compounds that, in addition to their essential 'weld through' properties, are also required for other specific uses, eg heat or fluid resistance or pressure sealing.

## CONCLUSIONS

1. Test Conditions to evaluate weld through primers have been established. When several types of compounds were examined the conditions required for satisfactory welding were generally too varied to be encompassed in a specification. Only three compounds were used for the majority of the tests.

2. Two Polyester based compounds, PRI3 and LS5319, were considered to be satisfactory for a general purpose weld through primer whereas F580/SD/89968, a modified chromated epoxy primer, would be useful if short open and closed times could be tolerated.

3. In the corrosion test these three compounds were not completely effective in preventing corrosion although there was a marked improvement over control specimens without primer.

4. The effect of corrosion in a spot welded joint was to reduce the shear strength. For clad alloys the reduction was too small to be considered as a specification test. For the unclad alloy L71, consistent results were obtained and this could be considered as a specification test for evaluating the corrosion preventative properties of weld through primers.

5. Surface resistance measurement was a useful criterion to determine the effects of pickling solutions and compounds.

5.1 Both clad and unclad alloys could be pickled to give a surface resistance of 20 micro-ohms or less. After such pickling conditions this resistance did not increase to above 40 micro-ohms after ageing for ten days.

5.2 Aloclene 100 was the most suitable pickle for the clad alloys. The range of pickle times to give a surface resistance of 20 micro-ohms varies according to the alloy and gauge of alloy.

5.3 For the unclad alloy L71, the 2 per cent nitric acid pickle used at 75°C was found to be most suitable.

5.4 Using pickle times established by the surface resistance measurements, satisfactory welding was carried out on clad and unclad alloys.

5.5 Surface resistance measurements on aluminium alloys coated with primers were a useful guide to the subsequent welding tests although the readings obtained were often much higher than those without primer.

6. The correlation of the three methods of weld inspection was not fully satisfactory.

TABLE 1

SUMMARY OF CONSISTENCY TEST RESULTS
30 SPECIMENS ON EACH TEST 2 WELDS EXAMINED ON EACH SPECIMEN

| Alloy | Gauge swg | Primer | Open Time in Hours | Closed Time | Shear Tests on 20 specimens | | | X-Ray Results on 30 Specimens (60 Welds) | Metallographic Results on 10 Specimens Number of Unsatisfactory Welds. 20 examined |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Minimum Proof Load Pounds | Failing Load in Pounds (Average) | Standard Deviation | | |
| L72 | 20 | None | - | - | 846 | 1259 | 2.8% | Satisfactory | 2 Excess penetration |
| L72 | 20 | PR13 | 2 hours | 2 days | 846 | 1278 | 2.7% | Satisfactory | 5 Excess penetration |
| L72 | 20 | LS5319 | 2 hours | 3 days | 846 | 1337 | 3.5% | Satisfactory | 3 Excess penetration |
| L72 | 20 | F580/SD/89968 | ½ hour | 2 hours | 846 | 1293 | 2.0% | 7 Unsatisfactory welds | 5 Excess penetration |
| L73 | 20 | None | - | - | 846 | 1487 | 2.9% | Satisfactory | 17 Excess penetration |
| L73 | 20 | PR13 | 2 hours | 3 days | 846 | 1435 | 3.7% | Satisfactory | 15 Excess penetration |
| DTD5070A | 20 | None | - | - | Not known | 1264 | 1.8% | 1 Unsatisfactory weld | 2 Excess penetration |
| DTD5070A | 20 | PR13 | 2 hours | 3 days | Not known | 1326 | 2.5% | Satisfactory | 3 Excess penetration + Porosity cracking |
| L71 | 20 | None | - | - | Not known | 1341 | 2.5% | Satisfactory | None |
| L71 | 20 | PR13 | 2 hours | 3 days | Not known | 1306 | 2.2% | Satisfactory | None |
| L71 | 20 | LS5319 | 2 hours | 3 days | Not known | 1412 | 2.9% | Satisfactory | None |
| L71 | 20 | F580/SD/89968 | ½ hour | 2 hours | Not known | 1344 | 2.3% | Satisfactory | None |

TABLE 1 (Continued)

SUMMARY OF CONSISTENCY TEST RESULTS
30 SPECIMENS ON EACH TEST 2 WELDS EXAMINED ON EACH SPECIMEN

| Alloy | Gauge swg | Primer | Open Time in Hours | Closed Time | Shear Tests on 20 specimens | | | X-Ray Results on 30 Specimens (60 Welds) | Metallographic Results on 10 Specimens Number of Unsatisfactory Welds. 20 examined |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Minimum Proof Load Pounds | Failing Load In Pounds (Average) | Standard Deviation | | |
| L72 | 24 | None | - | - | 360 | 537 | 2.1% | Satisfactory | None |
| L72 | 24 | PR13 | 2 hours | 3 days | 360 | 664 | 2.8% | 4 Unsatisfactory welds | 4 Lack of Fusion<br>2 Poor penetration + Poor shape |
| L73 | 24 | None | - | - | 360 | 589 | 4.4% | Satisfactory | 2 Excess penetration |
| L73 | 24 | PR13 | 2 hours | 3 days | 360 | 711 | 2.8% | 2 Unsatisfactory welds | 1 Lack of fusion<br>1 Poor penetration |
| DTD5070A | 22 | None | - | - | Not known | 1218 | 4.6% | Satisfactory | 20 Excess penetration |
| DTD5070A | 22 | PR13 | 2 hours | 3 days | Not known | 1175 | 4.5% | Satisfactory | 18 Excess penetration |

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TABLE 2
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TABLE 4

TABLE 2

X-RAY EXAMINATION OF SPOT WELDS IN CORROSION TESTS
6C WELDS EXAMINED FOR EACH TEST

TABLE 4

SPECIMENS WITH NO CORROSION (20 EXAMINED IN EACH TEST

| Alloy | Gauge swg | Primer | Acceptable Faults: Unsatisfactory Welds | Moderate Cracking | Small Cracks | Moderate Porosity | Slight Porosity | Porosity & Cracking | Poor Shape | Lack of Fusion | Number of Specimens with no Corrosion |
|---|---|---|---|---|---|---|---|---|---|---|---|
| L72 | 20 | None | - | - | 3 | - | - | - | - | 9 | None |
| L72 | 2C | PR13 | - | - | 1 | - | - | - | - | 1 | 6 |
| L72 | 20 | LS5319 | - | - | 3 | - | - | - | - | 8 | 14 |
| L72 | 20 | F580/SD/89968 | - | 1 | - | - | - | - | - | - | 11 |
| L73 | 20 | None | - | - | - | - | - | - | - | - | None |
| L73 | 20 | PR13 | - | - | - | - | - | - | - | 2 | None |
| DTD5070A | 20 | None | - | - | - | - | - | - | - | 5 | None |
| DTD5070A | 20 | PR13 | - | - | - | - | - | - | - | 5 | 6 |
| L71 | 20 | None | - | - | - | - | - | - | - | - | None |
| L71 | 20 | PR13 | - | - | - | - | - | - | - | - | None |
| L71 | 20 | LS5319 | - | - | - | - | - | - | - | 2 | 2 |
| L71 | 20 | F580/SD/89968 | - | - | - | - | - | - | - | 3 | None |
| L72 | 24 | None | - | - | - | - | - | - | - | - | None |
| L72 | 24 | PR13 | - | 1 | - | - | - | - | - | - | 4 |
| L73 | 24 | None | - | - | - | - | - | - | - | - | None |
| L73 | 24 | PR13 | - | - | - | - | - | - | - | - | 3 |
| DTD5070A | 22 | None | - | - | - | - | - | - | - | 1 | None |
| DTD5070A | 22 | PR13 | - | - | - | - | - | - | - | 1 | 2 |

TABLE 3

COMPARISON OF SHEAR STRENGTH OF CONSISTENCY TESTS AND CORROSION TEST

20 Specimens in Each Test Except 28 Week Corrosion Test - 4 Specimens

| | | | CONSISTENCY TESTS | | | CORROSION TESTS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Alloy | Gauge | Primer | Mean Shear Strength Pounds | Standard Deviation | % Effect of Primer | Duration of Corrosion Period in Weeks | Mean Shear Strength Pounds | Standard Deviation | % Effect of Primer | % Effect of Corrosion |
| L72 | 20 | None | 1259 | 2.8 | - | 22 | 1238 | 3.4 | - | -1.7 |
| L72 | 20 | PR13 | 1278 | 2.7 | +1.5 | 22 | 1272 | 3.6 | +2.7 | -0.5 |
| L72 | 20 | LS5319 | 1337 | 3.5 | +6.2 | 22 | 1259 | 2.9 | +1.7 | -5.9 |
| L72 | 20 | F580/SD/89968 | 1293 | 2.0 | +2.7 | 22 | 1239 | 2.9 | +0.1 | -3.7 |
| L73 | 20 | None | 1487 | 2.9 | - | 22 | 1423 | 3.2 | - | -4.3 |
| L73 | 20 | PR13 | 1435 | 3.7 | -3.5 | 22 | 1403 | 2.5 | -1.4 | -2.2 |
| DTD5070A | 20 | None | 1264 | 1.8 | - | 22 | 1292 | 2.6 | - | +2.2 |
| DTD5070A | 20 | PR13 | 1326 | 2.5 | +4.9 | 22 | 1391 | 2.2 | +7.7 | +4.9 |
| 71 | 20 | None | 1341 | 2.5 | - | 22 | 1201 | 3.9 | - | -10.4 |
| | | | | | | 28 | 1131 | | - | -15.6 |
| L71 | 20 | PR13 | 1306 | 2.2 | -2.6 | 22 | 1236 | 2.9 | +2.9 | -5.3 |
| | | | | | | 28 | 1188 | | +5.0 | -9.0 |
| L71 | 20 | LS5319 | 1412 | 2.9 | +5.3 | 22 | 1355 | 3.7 | +12.8 | -4.0 |
| | | | | | | 28 | 1346 | | +10.2 | -4.7 |
| L71 | 20 | F580/SD/89968 | 1344 | 2.3 | +0.2 | 22 | 1510 | 6.3 | +25.6 | +12.4 |
| | | | | | | 28 | 1469 | | +29.7 | +9.3 |

TABLE 3 (continued)

COMPARISON OF SHEAR STRENGTH OF CONSISTENCY TESTS AND CORROSION TEST

20 Specimens in Each Test Except 28 Week Corrosion Test - 4 Specimens

| | | | CONSISTENCY TESTS | | | CORROSION TESTS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Alloy | Gauge | Primer | Mean Shear Strength Pounds | Standard Deviation | % Effect of Primer | Duration of Corrosion Period in Weeks | Mean Shear Strength Pounds | Standard Deviation | % Effect of Primer | % Effect of Corrosion |
| L72 | 24 | None | 537 | 2.1 | - | 22 | 557 | 5.3 | - | +3.7 |
| L72 | 24 | PR13 | 664 | 2.8 | +23.6 | 22 | 654 | 5.0 | +17.4 | -1.5 |
| L73 | 24 | None | 589 | 4.4 | - | 22 | 559 | 2.8 | - | -5.1 |
| L73 | 24 | PR13 | 711 | 2.8 | +20.7 | 22 | 626 | 4.7 | +12.0 | -8.8 |
| DTD5070A | 22 | None | 1218 | 2.8 | - | 22 | 1106 | 5.0 | - | -9.2 |
| | | | | | | 28 | 1094 | | - | -10.2 |
| DTD5070A | 22 | PR13 | 1175 | 4.6 | -3.5 | 22 | 1063 | 4.6 | -3.9 | -9.5 |
| | | | | | | 28 | 1074 | | -1.8 | -9.4 |

TABLE 5

METALLOGRAPHIC EXAMINATION OF CORRODED SPOT/WELD/SPECIMENS

5 Most Corroded Specimens Examined out of 20

| Alloy | Gauge swg | Primer | Maximum Depths of Corrosion in inches x $10^3$ | Average | Comments |
|---|---|---|---|---|---|
| L72 | 20 | None | 1.0, 2.0, 1.5, 1.0, 1.5 | 1.4 | No inter crystalline corrosion |
| L72 | 20 | PR13 | 1.0, 2.0, 1.5, 1.0, 2.0 | 1.5 | No inter crystalline corrosion |
| L72 | 20 | LS5319 | 1.0, 2.0, 0.5, 2.5, 0.5 | 1.3 | No inter crystalline corrosion |
| L72 | 20 | F580/SD/ 89968 | 1.0, 1.5, 1.0, 1.5, 2.0 | 1.4 | No inter crystalline corrosion |
| L73 | 20 | None | 2.5, 2.5, 1.7, 3.5, 1.5 | 2.3 | Pitting, some inter crystalline corrosion |
| L73 | 20 | PR13 | 1.5, 1.4, 1.4, 1.4, 1.5 | 1.4 | Pitting |
| DTD 5070A | 20 | None | 2.0, 2.0, 2.0, 4.0, 3.0 | 2.5 | General surface attack |
| L71 | 20 | None | 36.0 (5) | 36.0 | 9 specimens with corrosion completely through metal |
| L71 | 20 | PR13 | 2.0, 12.0, 10.0, 8.0, 10.0 | 8.0 | Inter crystalline corrosion on all 5 specimens |
| L71 | 20 | LS5319 | 8.0, 6.0, 3.5, 6.0, 25.0 | 9.7 | Inter crystalline corrosion on 4 specimens |
| L71 | 20 | F580/SD/ 89968 | 10.0, 2.5, 7.5, 4.5, 3.0 | 5.5 | Inter crystalline corrosion on 5 specimens |
| L72 | 24 | None | 2.0, 1.0, 2.0, 1.0, 1.0 | 1.4 | Slight surface attack |
| L72 | 24 | PR13 | 0.5, 1.0, 2.0, 1.0, 1.0 | 1.1 | Slight surface attack |
| L73 | 24 | None | 1.7, 1.7, 4.0, 5.0, 2.0 | 2.9 | Pitting, inter crystalline corrosion on 4 specimens |
| L73 | 24 | PR13 | 1.3, 4.0, 1.1, 1.3, 1.8 | 1.9 | Pitting, inter crystalline corrosion on 2 specimens |
| DTD 5070A | 22 | None | 5.5, 2.1, 2.5, 2.0, 2.5 | 2.9 | Pitting, inter crystalline corrosion. Exfoliation on 3 specimens |
| DTD 5070A | 22 | PR13 | 1.1, 2.4, 2.5, 2.0, 2.0 | 2.0 | Pitting |

FIGURE 1 APPARATUS FOR MEASURING SURFACE RESISTANCE

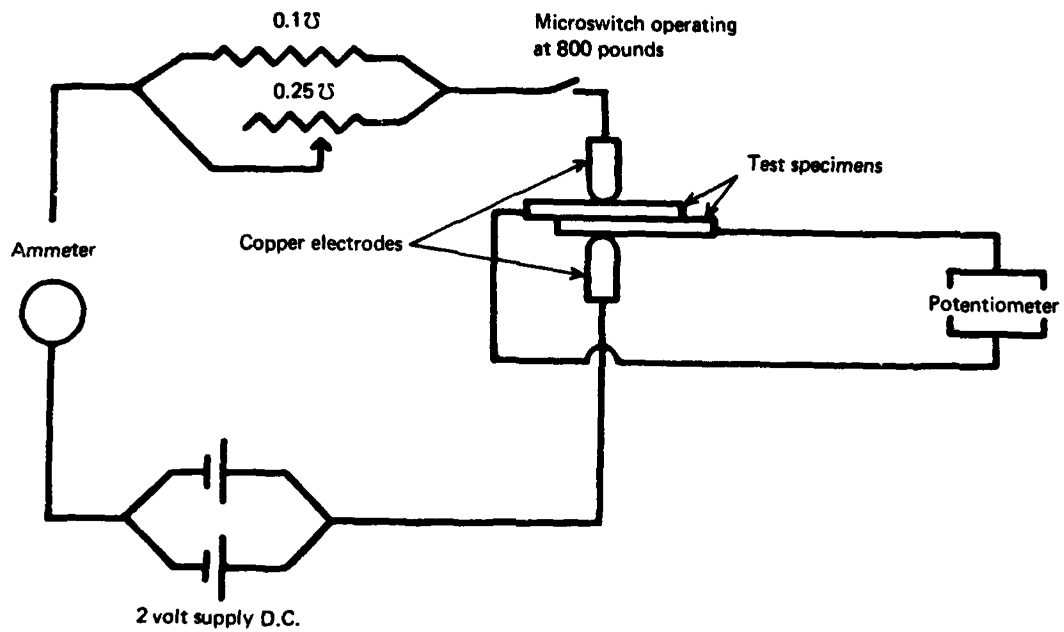
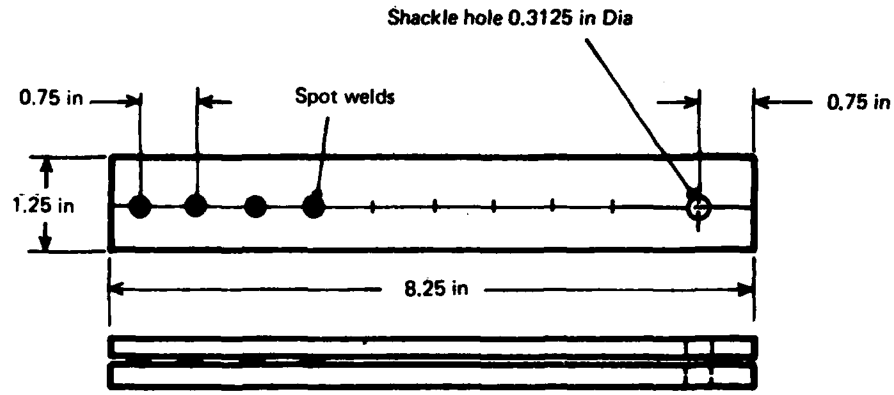
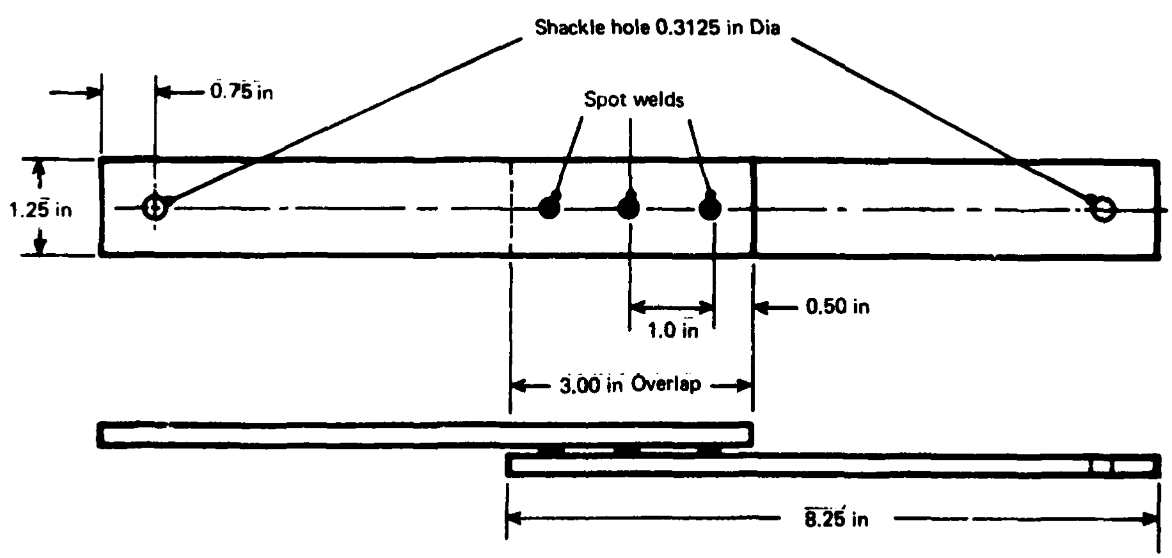


FIGURE 2 PRELIMINARY TEST SPECIMEN (TYPE 1)




K4364 A

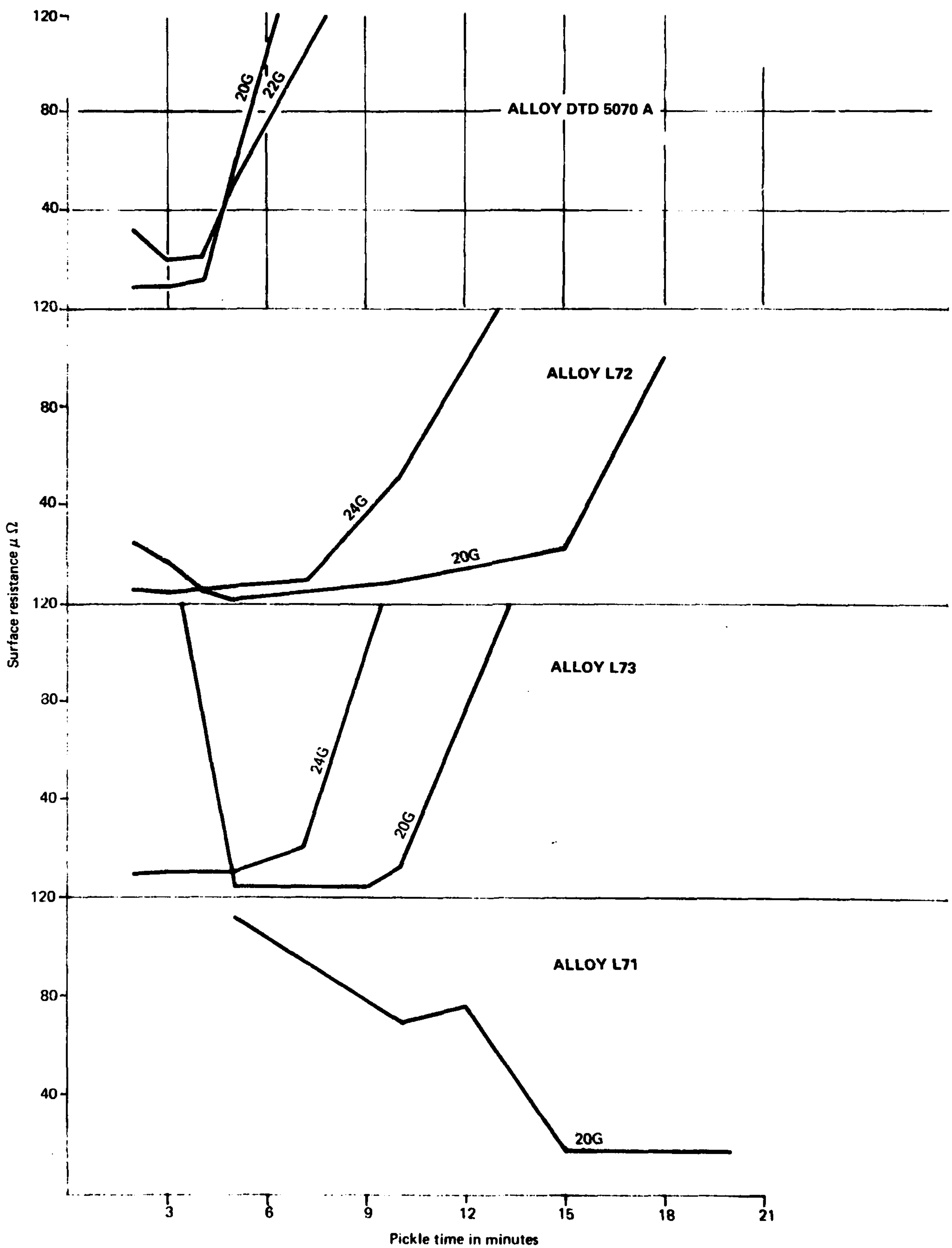
FIGURE 3 CONSISTENCY TEST SPECIMEN (TYPE 2)



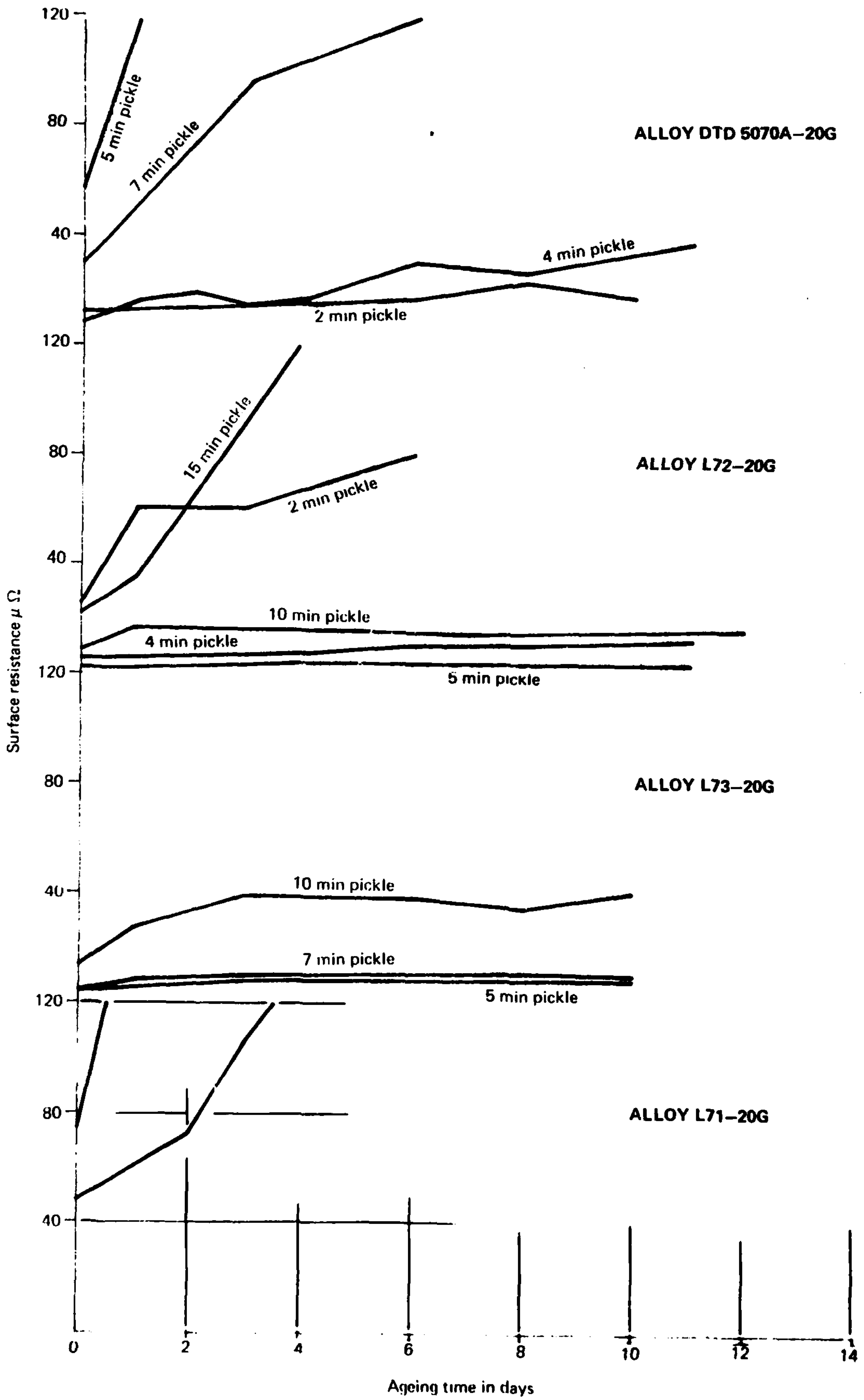

K4365 A

FIGURE 4

PICKLE : ALOCLENE 100 SURFACE RESISTANCE/PICKLE TIME



PICKLE : ALOCLENE 100 AGEING TIME/SURFACE RESISTANCE



PICKLE : ALOCLENE 100 AGEING TIME/SURFACE RESISTANCE FIGURE 6

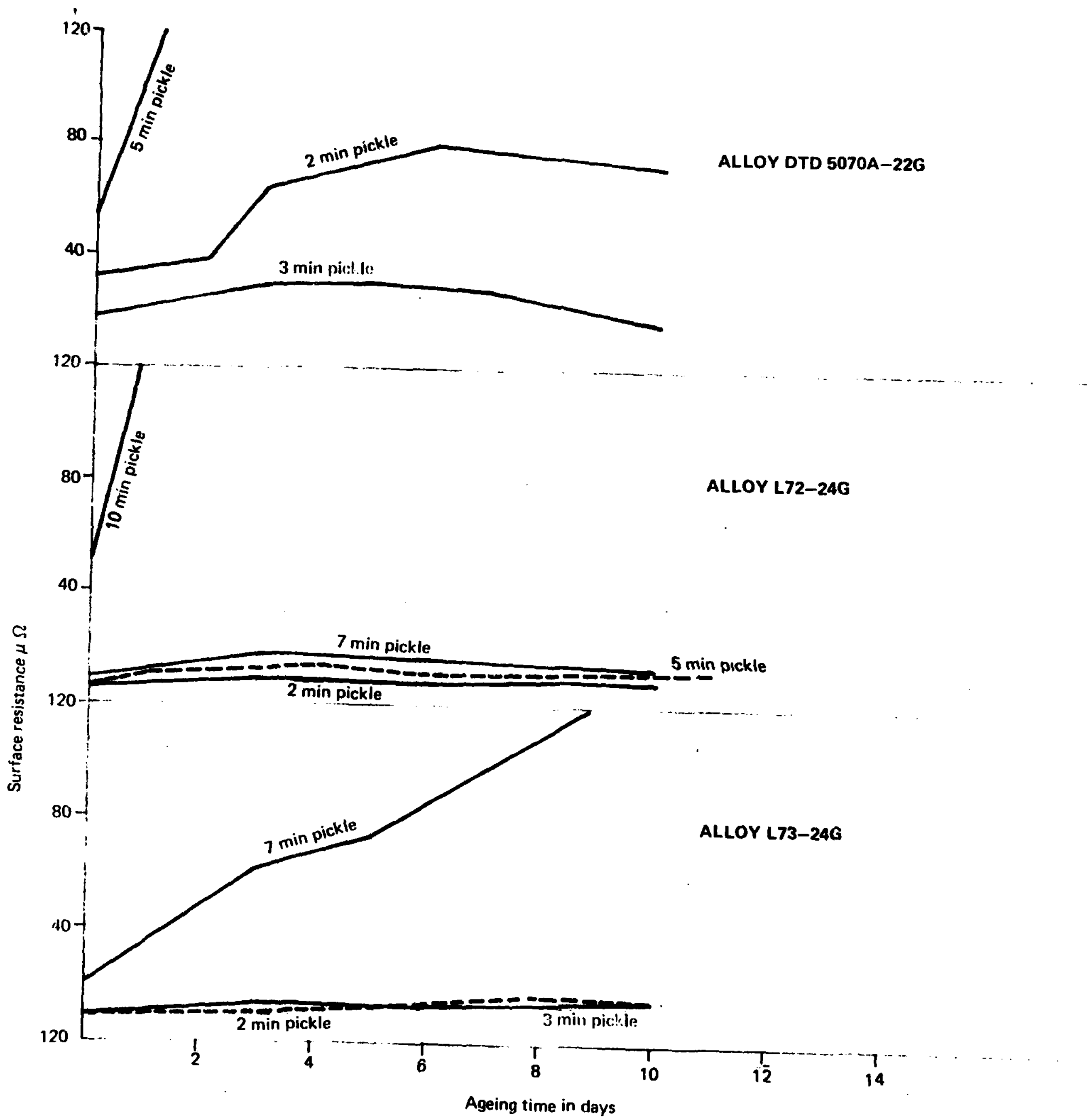
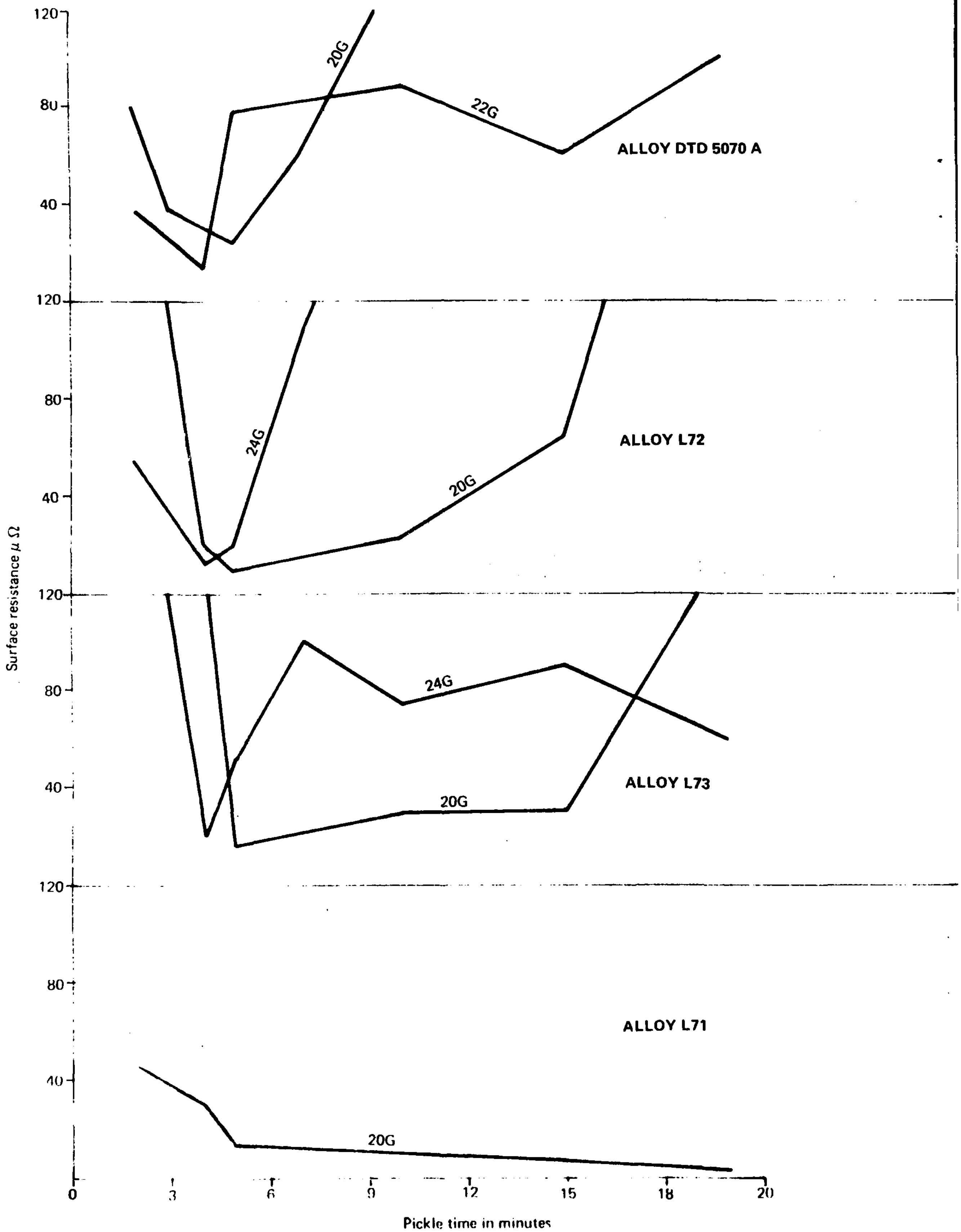


FIGURE 7

PICKLE : 2% NITRIC ACID SURFACE RESISTANCE/PICKLE TIME



PICKLE : 2% NITRIC ACID AGEING TIME/SURFACE RESISTANCE

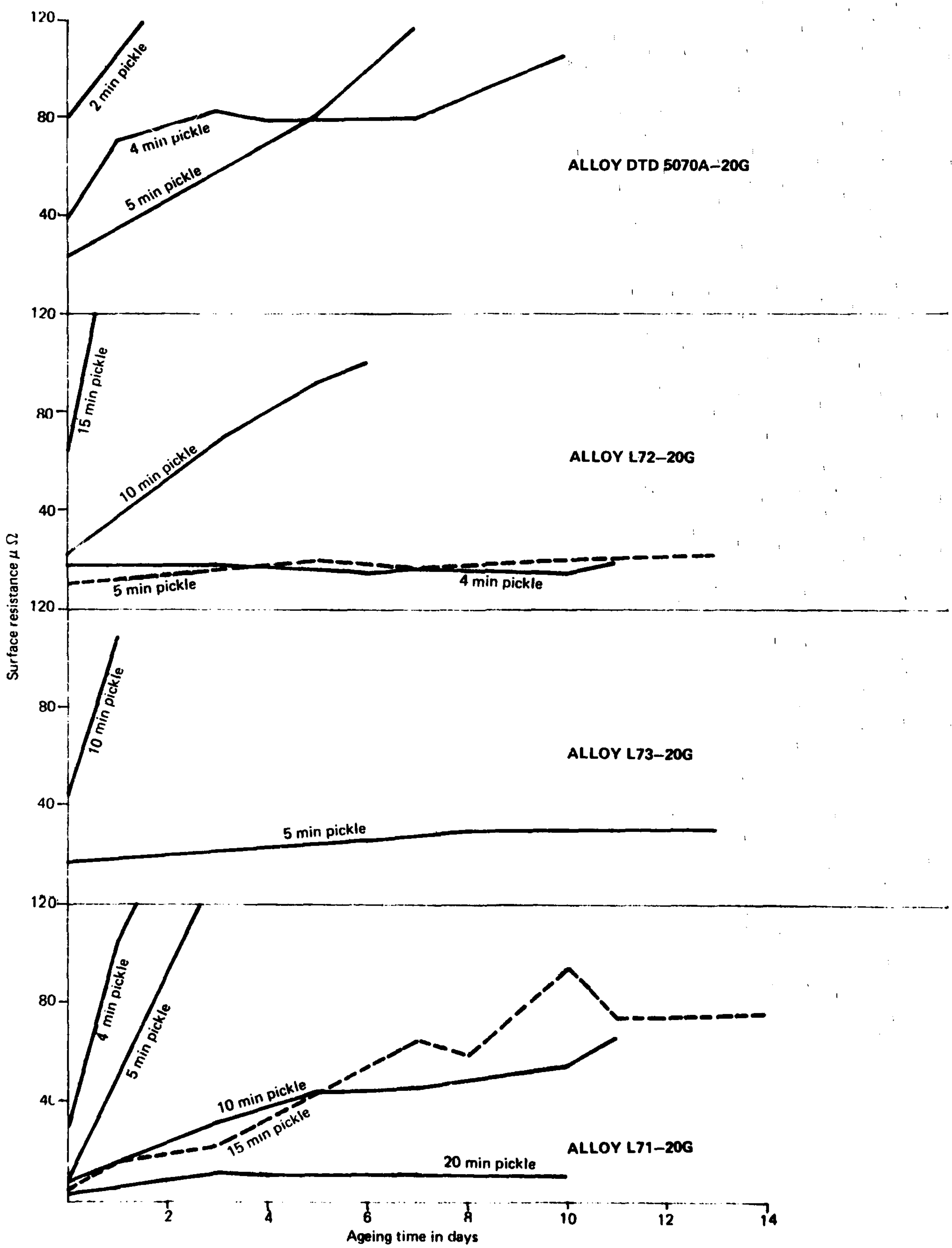


FIGURE 9 PRIMER PR 13 OPEN TIME/SURFACE RESISTANCE

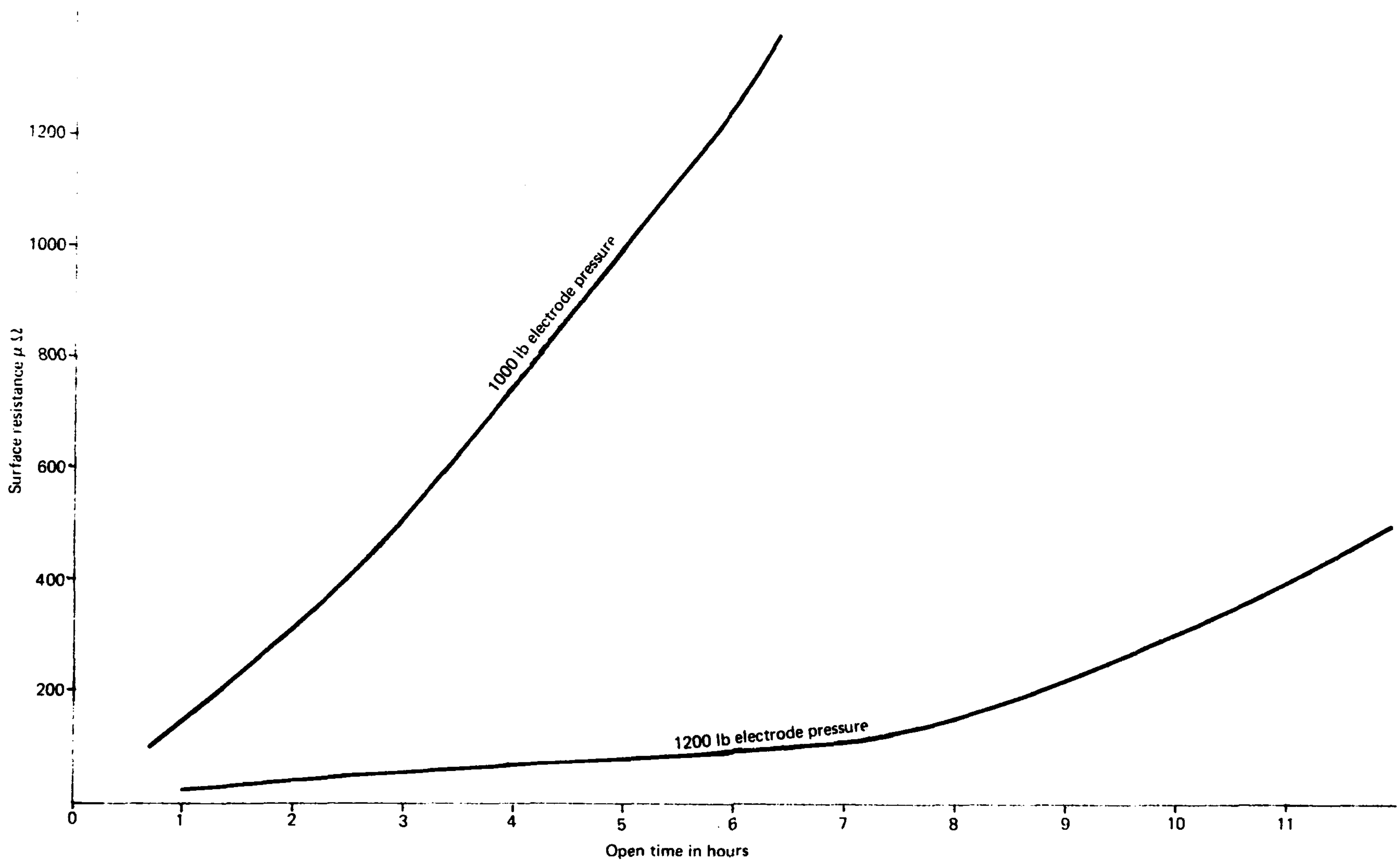



FIGURE 9

FIGURE 10 PRIMER PR 13 CLOSED TIME/SURFACE RESISTANCE

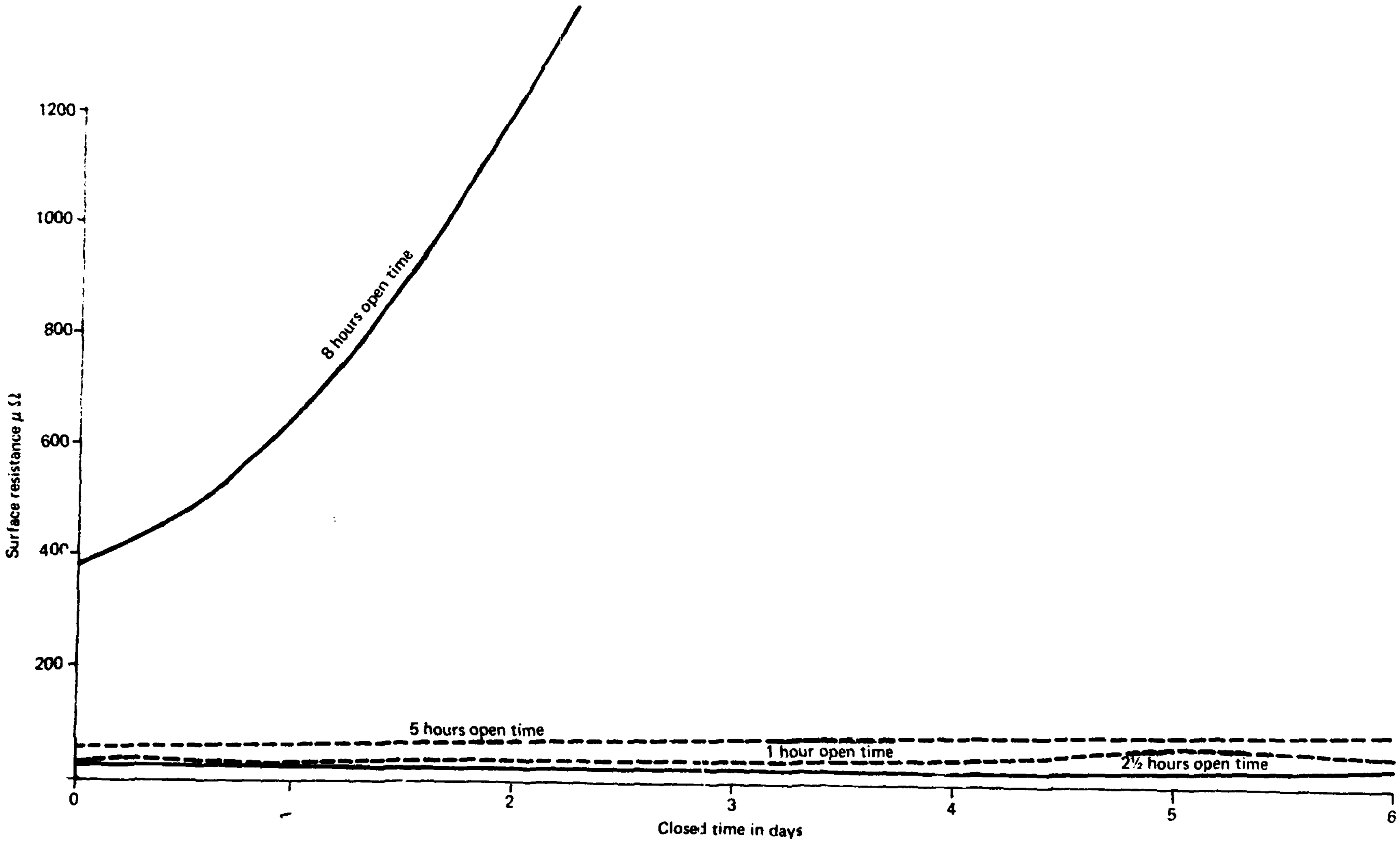



FIGURE 10

FIGURE 11

OPEN TIME/SURFACE RESISTANCE
USING PRIMER F580 SD 89968 WITH DIFFERENT ACTIVATORS

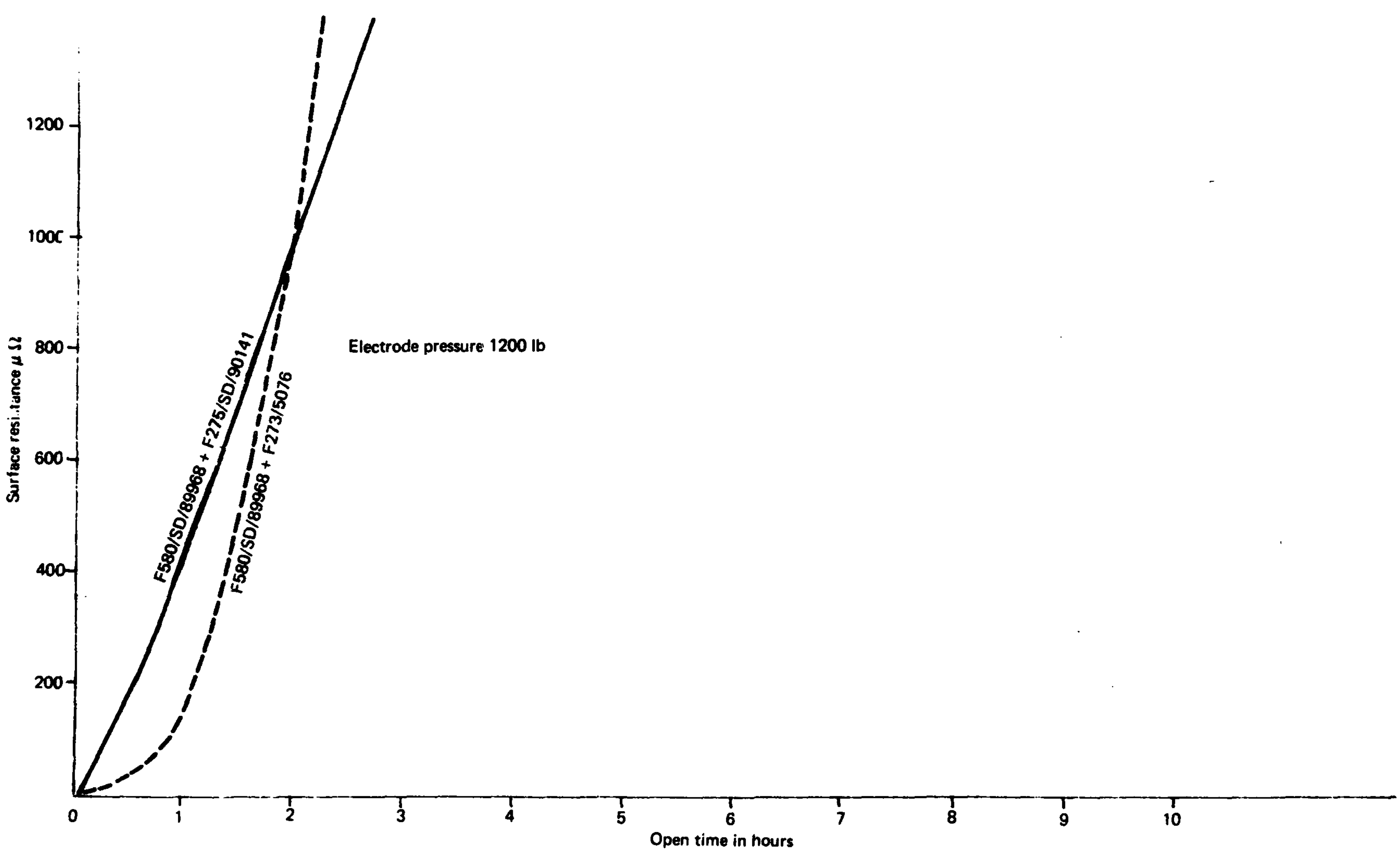



FIGURE 11